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Lee et al.

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(54) **LIQUID CRYSTAL DISPLAY**

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(51) **Int. Cl.**

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G02F 1/1343	(2006.01)
G02F 1/1333	(2006.01)

(52) **U.S. Cl.**

CPC ... ***G02F 1/134309*** (2013.01); ***G02F 1/133345*** (2013.01); *G02F 2001/134345* (2013.01)

(58) **Field of Classification Search**

CPC G02F 1/134309; G02F 1/133345

See application file for complete search history.

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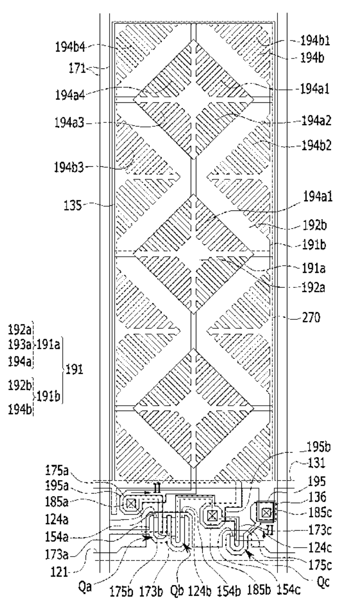
(57) **ABSTRACT**

A liquid crystal display according to an embodiment includes: a lower panel including a pixel electrode having a first subpixel electrode and a second subpixel electrode and an insulating layer between the first subpixel electrode and the second subpixel electrode; an upper panel including a common electrode; and a liquid crystal layer disposed between the lower panel and the upper panel. The first subpixel electrode includes a first plate portion, a first stem having a cross portion extending from the first plate portion and a protrusion extending from the cross portion, and a plurality of first branches extending from the first plate portion and the first stem. The second subpixel electrode includes a second plate portion having an opening and a plurality of second branches extending from the second plate portion. The cross portion does not overlap with the second plate portion. The protrusion overlaps with the second plate portion.

14 Claims, 15 Drawing Sheets



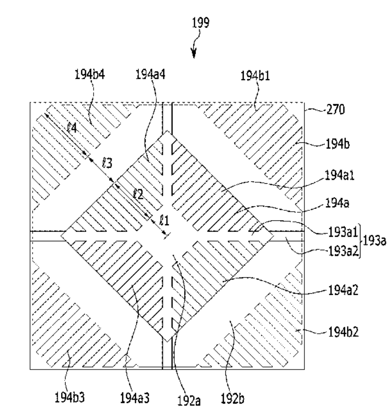
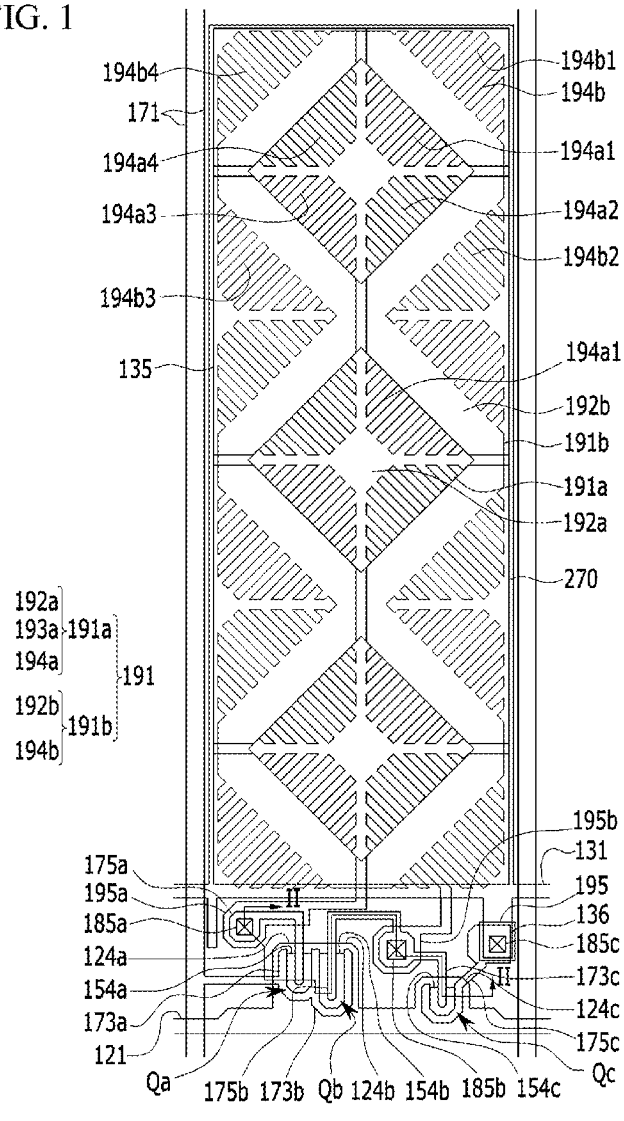


FIG. 1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194a3
194b3
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194a1
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192a
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192a
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191a
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192b
194b
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136
185c
173c
124c
175c
Qc
175a
195a
185a
124a
154a
173a
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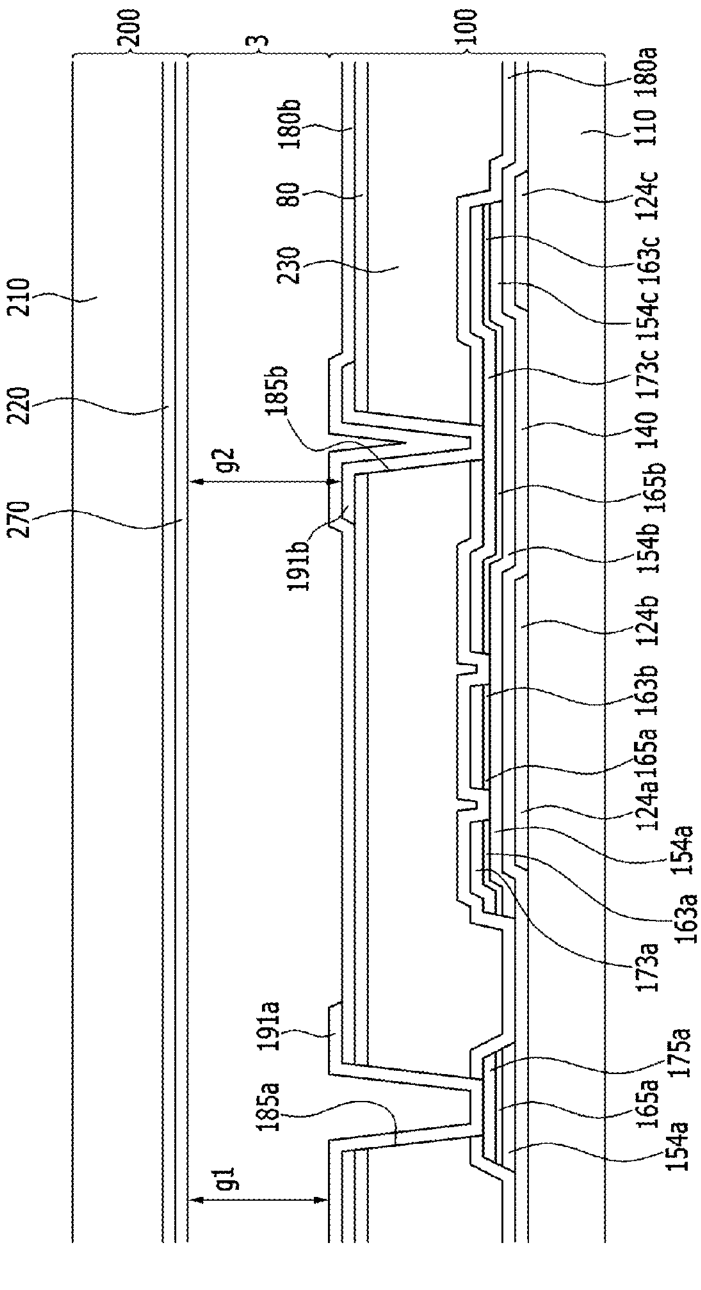
Qa
175b
173b
Qb
124b
154b
185b
154c
II
II

FIG. 2


200
3
100
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220
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180b
80
230
185b
g2
191b
191a
185a
g1
180a
110
124c
163c
154c
173c
140
165b
154b
124b
163b
124a
165a
154a
163a
173a
175a
165a
154a

FIG. 3

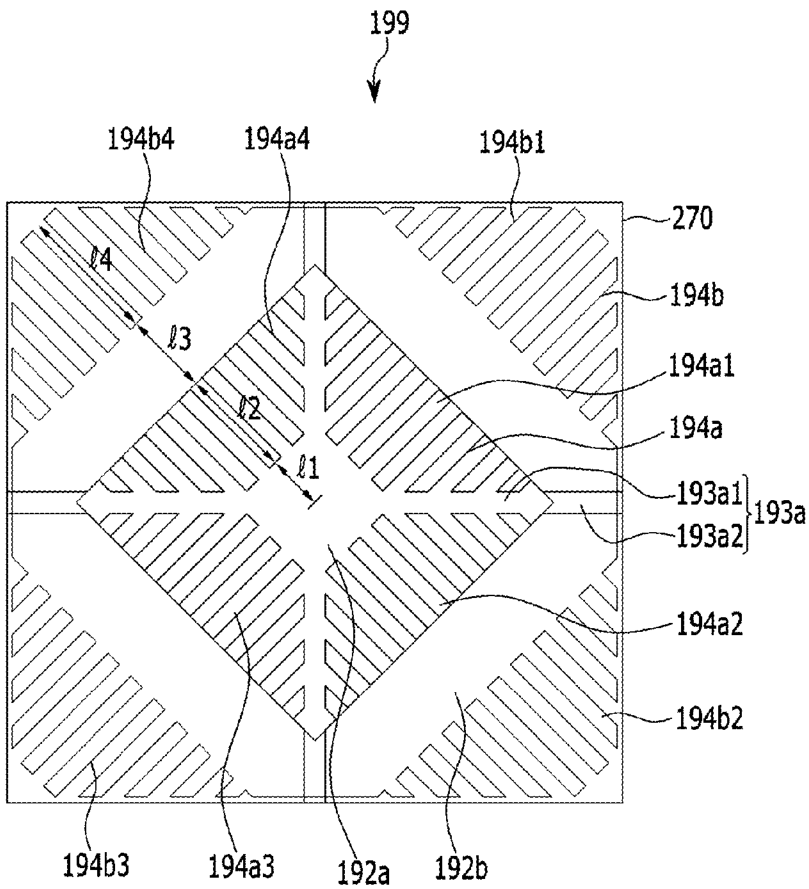

199
194b4
194a4
194b1
270
194b
194a1
194a
193a1
193a
193a2
194a2
194b2
ℓ4
ℓ3
ℓ2
ℓ1
194b3
194a3
192a
192b

FIG. 4

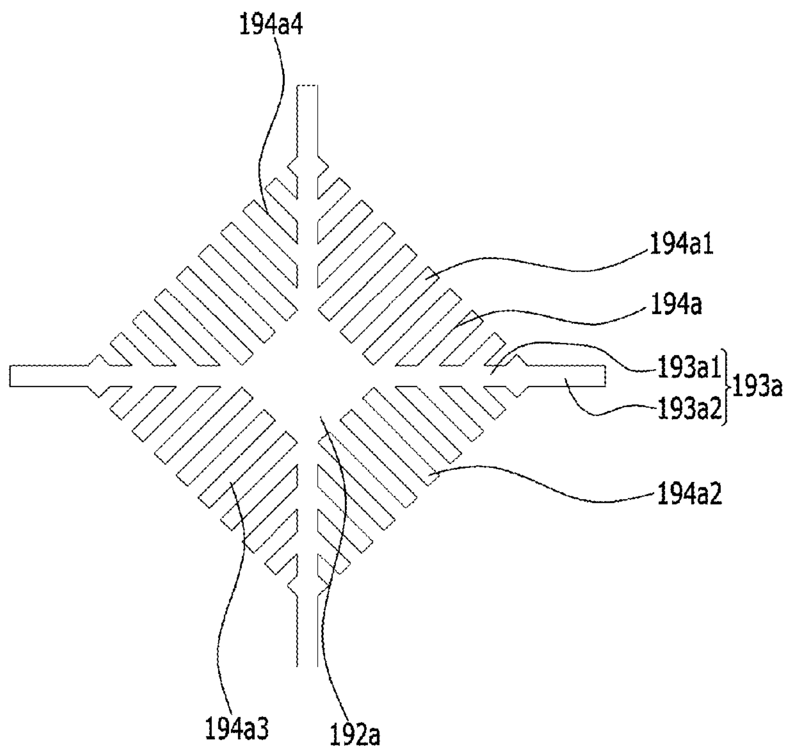


FIG. 5

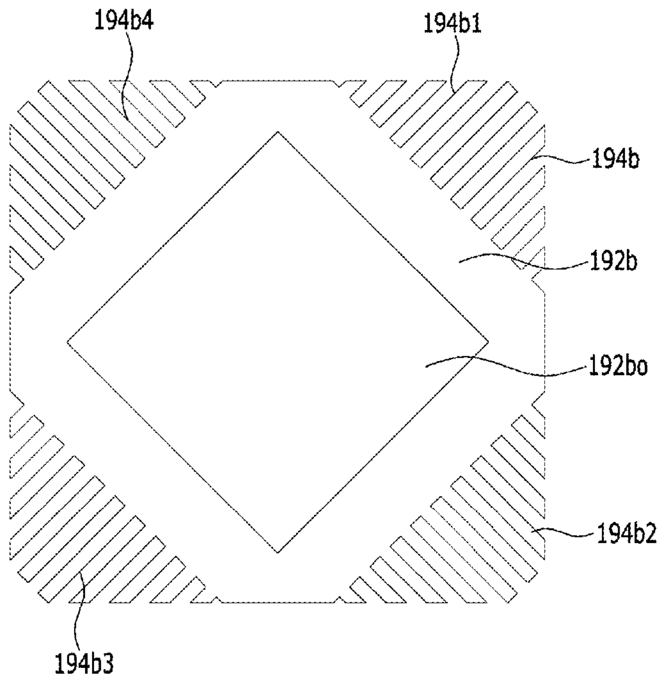


FIG. 6

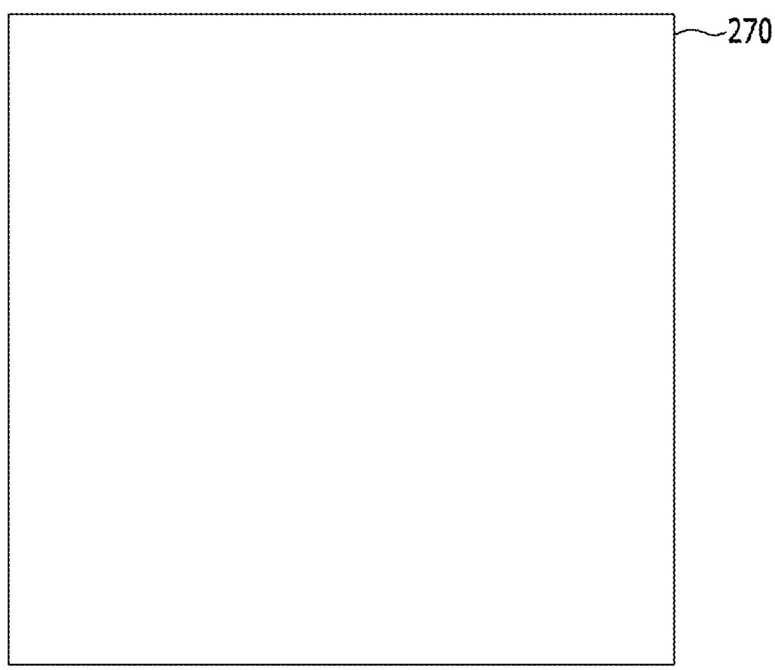


FIG. 7

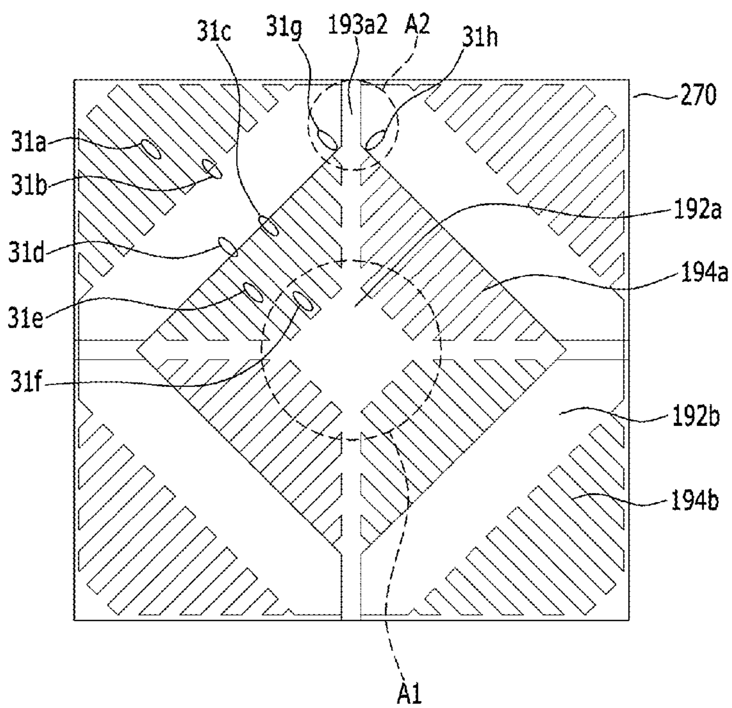
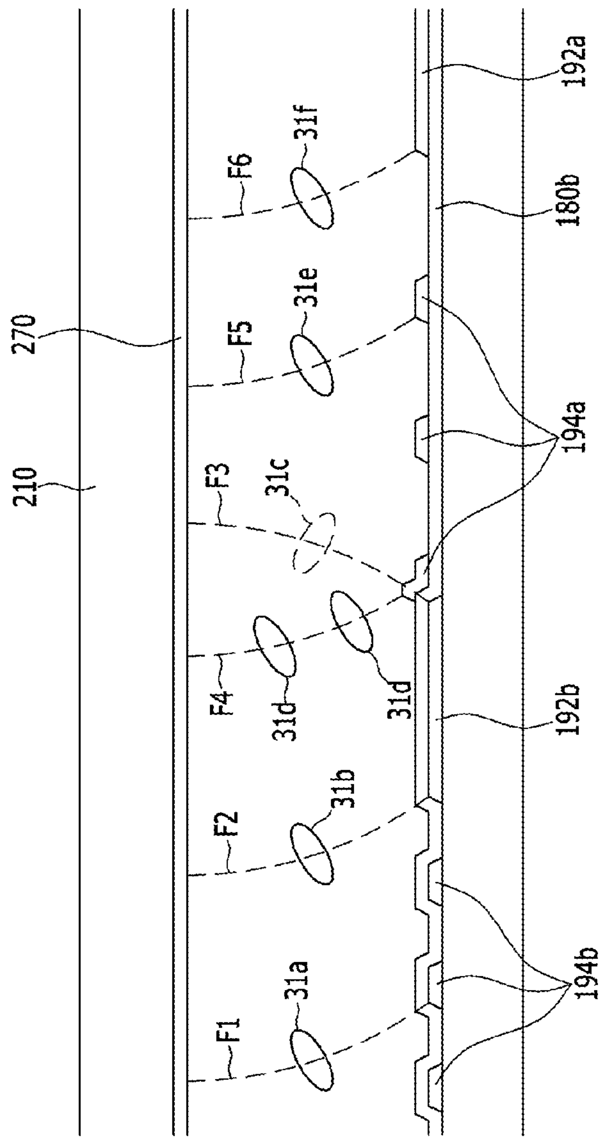

31c
31g
193a2
A2
31h
270
31a
31b
192a
31d
194a
31e
31f
192b
194b
A1

FIG. 8



270
210
192a
180b
194a
192b
194b
F1
F2
F3
F4
F5
F6
31a
31b
31c
31d
31d
31e
31f

FIG. 9

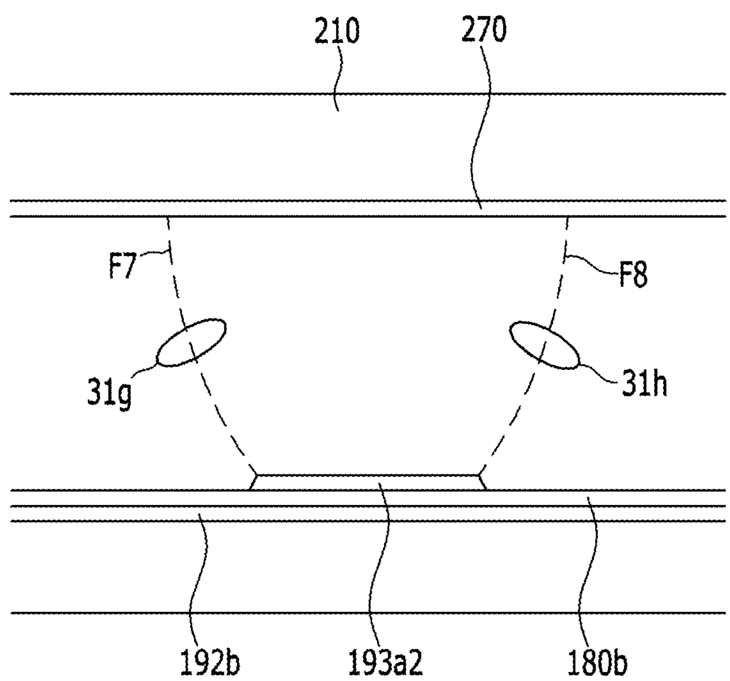
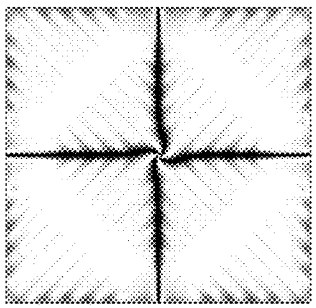
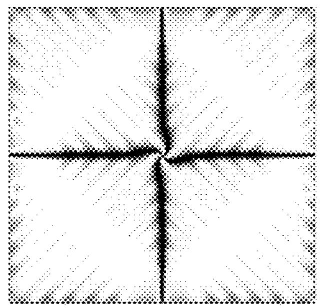


FIG. 10A



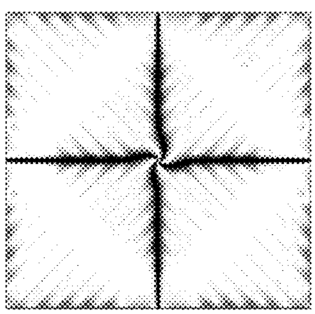
Voltage ratio 0.77

FIG. 10B



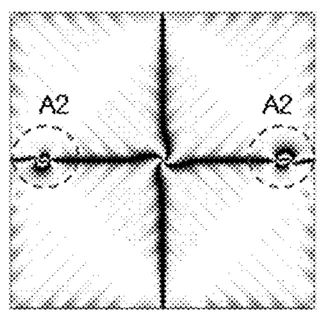
Voltage ratio 0.8

FIG. 10C



Voltage ratio 0.83

FIG. 10D



Voltage ratio 0.86

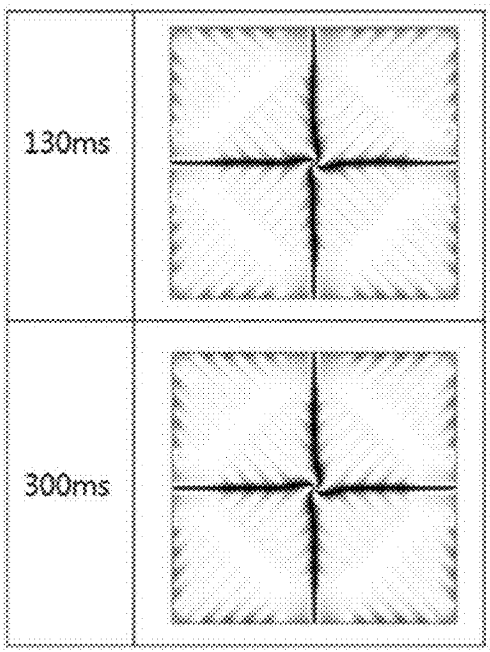


FIG. 11A

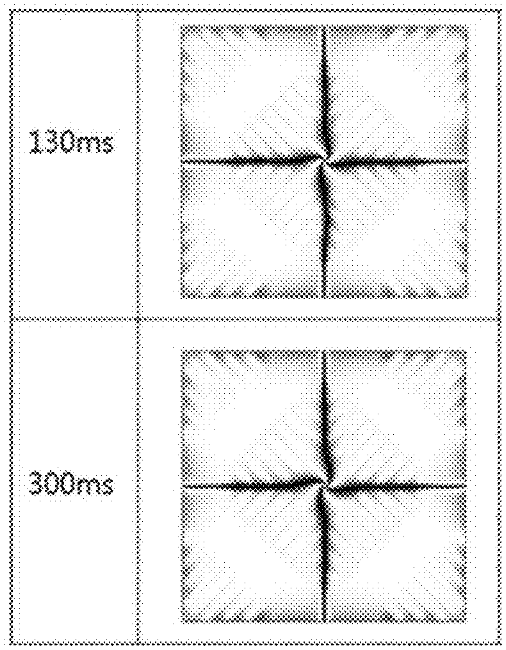


FIG. 11B

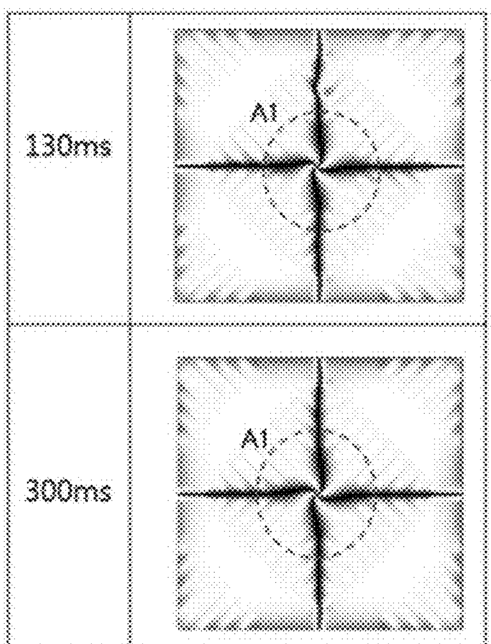
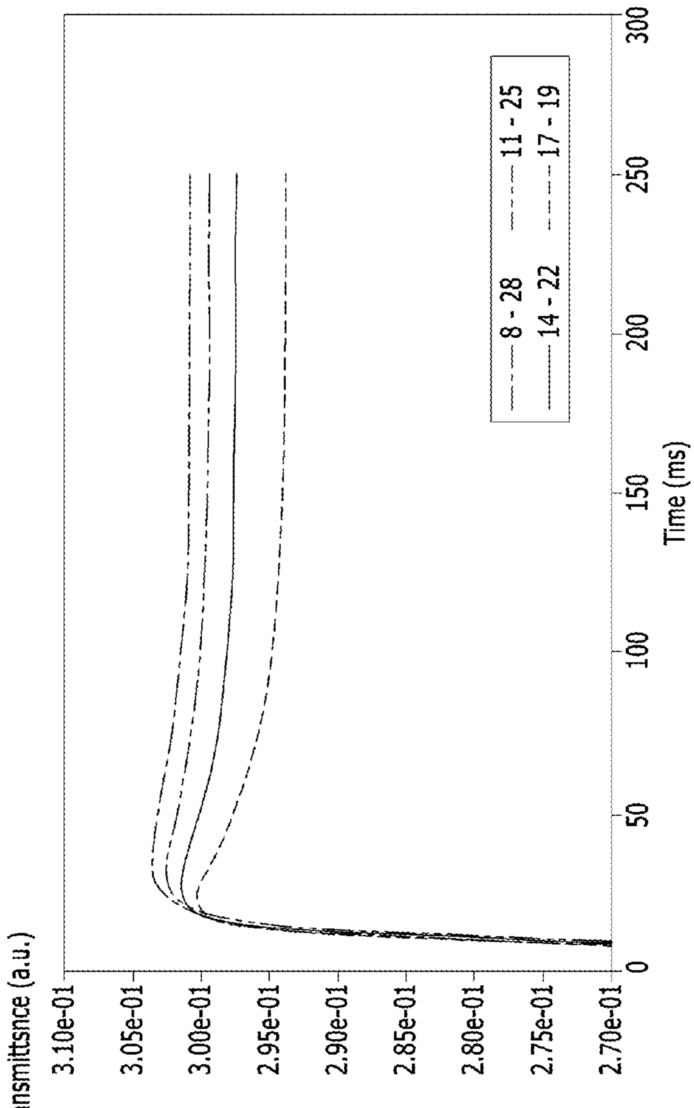


FIG. 11C

FIG. 12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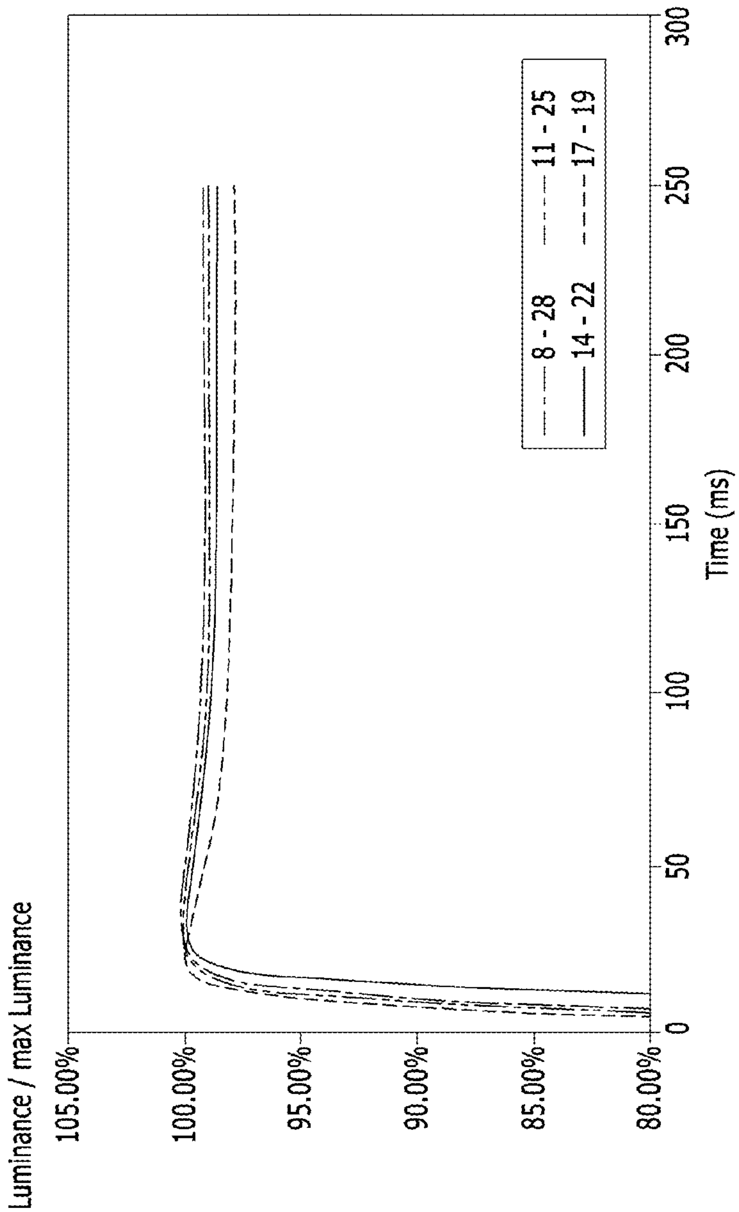
2.80e-01
2.75e-01
2.70e-01
0
50
100
150
200
250
300
Time (ms)
8 - 28
11 - 25
14 - 22
17 - 19

FIG. 13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100.00%
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90.00%
85.00%
80.00%
0
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100
150
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Time (ms)
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14 - 22
17 - 19

FIG. 14A

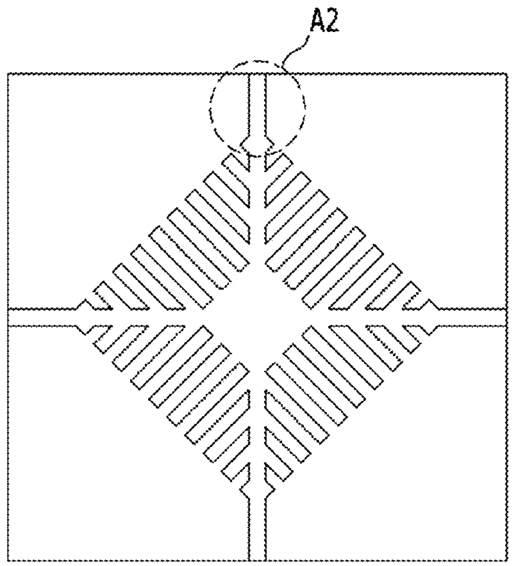


FIG. 14B

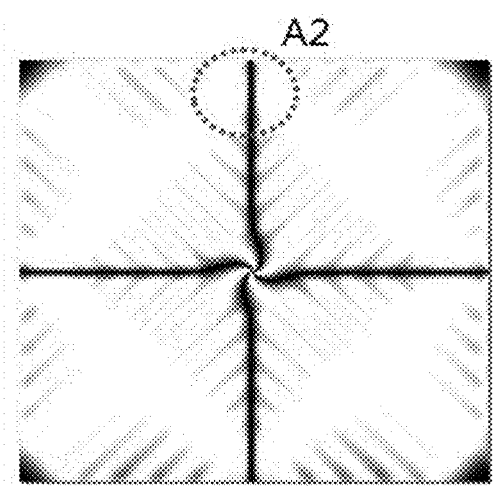


FIG. 15A

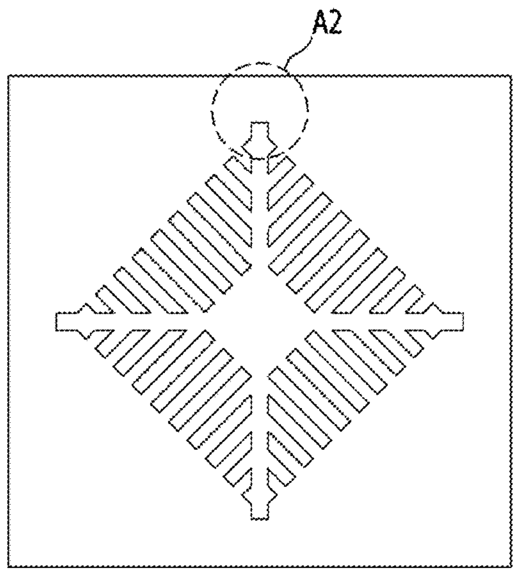
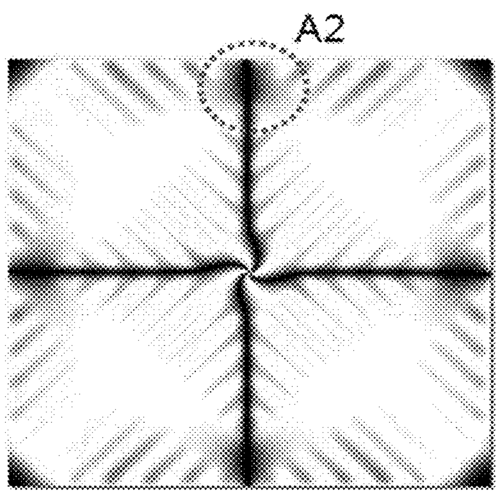


FIG. 15B



LIQUID CRYSTAL DISPLAY

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to and the benefit of Korean Patent Application No. 10-2014-0165474 filed in the Korean Intellectual Property Office on Nov. 25, 2014, the entire contents of which are incorporated herein by reference.

BACKGROUND

(a) Technical Field

The present disclosure relates to a liquid crystal display.

(b) Description of the Related Art

A liquid crystal display generally includes two sheets of panels with field generating electrodes such as a pixel electrode, a common electrode, and the like, and a liquid crystal layer interposed between the two sheets of panels. The liquid crystal display generates an electric field in the liquid crystal layer by applying a voltage to the field generating electrodes. The strength of the generated electric field determines the alignment direction of the liquid crystal molecules in the liquid crystal layer, which in turn determines the polarization of incident light by the liquid crystal layer. Thus, by controlling the voltage being applied to the field generating electrodes, thereby controlling the strength of the generated electric field, the liquid crystal display controls the polarization of incident light to display images.

A vertically aligned mode liquid crystal display is a liquid crystal display in which the long axis of the liquid crystal molecules is aligned perpendicular to a planar surface of the display panels while the electric field is not applied. To provide a wide viewing angle for the vertically aligned mode liquid crystal display, a method of forming a plurality of domains in which the liquid crystal molecules in adjacent domains are tilted in different directions (e.g., forming cutouts such as minute slits in the field generating electrode, and the like) is used. Further, to suppress texturing or deterioration in luminance around a domain boundary, a method of forming cutouts or patterns in the common electrode is used.

Also, a method of improving the side visibility of the vertically aligned mode liquid crystal display to approximate its front visibility, a technology of varying transmittance by dividing one pixel into two subpixels and differently applying voltages of the two subpixels has been developed.

SUMMARY

The present disclosure provides a liquid crystal display having advantages of improved side visibility and improved light transmittance.

The present disclosure also provides a liquid crystal display having advantages of reducing deterioration in image quality that may occur due to misalignment of a lower panel and an upper panel.

An exemplary embodiment of the present system and method provides a liquid crystal display including: a lower panel including a pixel electrode having a first subpixel electrode and a second subpixel electrode and an insulating layer disposed between the first subpixel electrode and the second subpixel electrode; an upper panel including a common electrode; and a liquid crystal layer disposed between the lower panel and the upper panel. The first subpixel electrode may include a first plate portion, a first stem

having a cross portion extending from the first plate portion in a cross shape and a protrusion extending from the cross portion, and a plurality of first branches extending from the first plate portion and the first stem. The second subpixel electrode may include a second plate portion having an opening therein and a plurality of second branches extending from the second plate portion. The cross portion may be free from overlap with the second plate portion and the protrusion may overlap with the second plate portion.

The first subpixel electrode may be positioned on the insulating layer and the second subpixel electrode may be positioned below the insulating layer.

The common electrode may be formed as a plate.

The second plate portion may surround the plurality of first branches.

The opening of the second plate portion may have a planar, rhombus shape.

An edge of the first branch and an edge of the second plate portion adjacent to the first branch may coincide with each other.

An edge of the first branch and an edge of the second plate portion adjacent to the first branch may overlap with each other.

The first plate portion may have a planar, rhombus shape.

A length corresponding to a distance from the center of the rhombus shaped first plate portion to one side may be about 14 μm or less.

The first stem may extend in a diagonal direction of the rhombus shaped first plate portion.

The first subpixel electrode may be configured to receive a first voltage, the second subpixel electrode may be configured to receive a second voltage, and a ratio of the second voltage to the first voltage may be about 0.83 or less.

The plurality of first branches may include a plurality of minute branches extending in four different directions, and the plurality of second branches may include a plurality of minute branches extending in the four different directions.

The four different directions may be orthogonal to each other or parallel to each other.

The plurality of first branches may extend from portions of the first stem excluding the protrusion.

According to the liquid crystal display of the present system and method, it is possible to suppress texturing without deteriorating transmittance while approximating side visibility to front visibility. Further, since cutouts need not to be formed in the common electrode to improve the control force of the liquid crystal molecules, texturing or deterioration in transmittance due to misalignment of the cutouts of the common electrode and the pixel electrode does not occur.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a layout view of a liquid crystal display, according to an exemplary embodiment of the present system and method.

FIG. **2** is a cross-sectional view of the liquid crystal display of FIG. **1** taken along line II-II.

FIG. **3** is a plan view illustrating a basic electrode of a field generating electrode of the liquid crystal display exemplified in FIG. **1**.

FIG. **4** is a plan view illustrating a first subpixel electrode separated from the basic electrode of the field generating electrode of FIG. **3**.

FIG. **5** is a plan view illustrating a second subpixel electrode separated from the basic electrode of the field generating electrode of FIG. **3**.

FIG. **6** is a plan view illustrating a common electrode separated from the basic electrode of the field generating electrode of FIG. **3**.

FIG. **7** is a schematic view illustrating alignment directions of directors of the liquid crystal molecules of the liquid crystal display according to an exemplary embodiment of the present system and method.

FIGS. **8** and **9** are cross-sectional views illustrating alignment directions of directors of the liquid crystal molecules of the liquid crystal display according to an exemplary embodiment of the present system and method.

FIGS. **10**A, **10**B, **10**C and **10**D are electron microphotographs illustrating results of a first experimental example of the present system and method.

FIGS. **11**A, **11**B and **11**C are electron microphotographs illustrating results of a second experimental example of the present system and method.

FIGS. **12** and **13** are graphs illustrating results of a third experimental example of the present system and method.

FIGS. **14**A, **14**B, **15**A and **15**B illustrate structures of a first subpixel electrode, and corresponding electron microphotographs, used in a fourth experimental example and a result thereof.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The present system and method are described hereinafter with reference to the accompanying drawings in which exemplary embodiments are shown. Those of ordinary skill in the art would realize that the described embodiments may be modified in various different ways without departing from the spirit or scope of the present system and method.

In the drawings, the thickness of layers, films, panels, regions, etc., is exaggerated for clarity. When an element such as a layer, film, region, or substrate is referred to as being "on" another element, it may be directly on the other element, or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" another element, there are no intervening elements present.

A liquid crystal display according to an exemplary embodiment of the present system and method is described in detail with reference to the accompanying drawings.

FIG. **1** is a layout view of a liquid crystal display according to an exemplary embodiment of the present system and method. FIG. **2** is a cross-sectional view of the liquid crystal display of FIG. **1** taken along line II-II. FIG. **3** is a plan view illustrating a basic electrode of a field generating electrode of the liquid crystal display exemplified in FIG. **1**. FIG. **4** is a plan view illustrating a first subpixel electrode separated from the basic electrode of the field generating electrode of FIG. **3**. FIG. **5** is a plan view illustrating a second subpixel electrode separated from the basic electrode of the field generating electrode of FIG. **3**. FIG. **6** is a plan view illustrating a common electrode separated from the basic electrode of the field generating electrode of FIG. **3**.

Referring to FIGS. **1** to **6**, the liquid crystal display includes a lower panel **100** and an upper panel **200** facing each other, a liquid crystal layer **3** interposed between the two panels **100** and **200**, and a pair of polarizer films (not illustrated) attached to outer surfaces of the panels **100** and **200**.

First, the lower panel **100** is described.

A gate line **121**, a reference voltage line **131**, and a storage electrode **135** are formed on a first insulation substrate **110**. The gate line **121** mainly extends in a horizontal direction and transfers a gate signal.

The gate line **121** includes a first gate electrode **124***a*, a second gate electrode **124***b*, a third gate electrode **124***c*, and a wide end portion (not illustrated) for connection with other layers or an external driving circuit.

The reference voltage line **131** may extend in parallel with the gate line **121** and includes the storage electrode **135** surrounding a pixel area. The reference voltage line **131** may have an extension **136**. The extension **136** may be connected with a third drain electrode **175***c*, which is described below.

A gate insulating layer **140** is formed on the gate line **121**, the reference voltage line **131**, and the storage electrode **135**.

A first semiconductor **154***a*, a second semiconductor **154***b*, and a third semiconductor **154***c*, which may be made of amorphous or crystalline silicon, are formed on the gate insulating layer **140**.

A plurality of ohmic contacts **163***a*, **163***b*, **163***c*, **165***a*, **165***b*, and **165***c* is formed on the first semiconductor **154***a*, the second semiconductor **154***b*, and the third semiconductor **154***c*. If the semiconductors **154***a*, **154***b*, and **154***c* are oxide semiconductors, the ohmic contacts may be omitted.

On the ohmic contacts **163***a*, **163***b*, **163***c*, **165***a*, **165***b*, and **165***c* and the gate insulating layer **140**, a data line **171** including a first source electrode **173***a* and a second source electrode **173***b*, a first drain electrode **175***a*, a second drain electrode **175***b*, a third source electrode **173***c*, a third drain electrode **175***c* are formed. The constituent elements **171**, **173***a*, **173***b*, **173***c*, **175***a*, **175***b*, and **175***c* are herein referred to as a data conductor. The second drain electrode **175***b* is connected with the third source electrode **173***c*.

The first gate electrode **124***a*, the first source electrode **173***a*, the first drain electrode **175***a*, and the first semiconductor **154***a* together form a first switching element Qa, which is a thin film transistor. A channel of the thin film transistor is formed in the semiconductor portion between the first source electrode **173***a* and the first drain electrode **175***a*. Similarly, the second gate electrode **124***b*, the second source electrode **173***b*, the second drain electrode **175***b*, and the second semiconductor **154***b* together form a second switching element Qb, also a thin film transistor, and a channel of the thin film transistor is formed in the semiconductor portion between the second source electrode **173***b* and the second drain electrode **175***b*. Likewise, the third gate electrode **124***c*, the third source electrode **173***c*, the third drain electrode **175***c*, and the third semiconductor **154***c* together form a third switching element Qc, also a thin film transistor, and a channel of the thin film transistor is formed in the semiconductor portion between the third source electrode **173***c* and the third drain electrode **175***c*.

The first drain electrode **175***a*, and the second drain electrode **175***b*, a first passivation layer **180***a* are formed on the data line **171**.

The first passivation layer **180***a* made of an inorganic insulating material, such as silicon nitride or silicon oxide, is formed on the data conductor **171**, **173***a*, **173***b*, **173***c*, **175***a*, **175***b*, **175***c* and the exposed portions of the semiconductors **154***a*, **154***b*, and **154***c*.

A color filter **230** is formed on the first passivation layer **180***a*. A light blocking member (not illustrated) may be positioned on a region where the color filter **230** is not positioned and overlap a part of the color filter **230**. The light blocking member is herein referred to as a black matrix and blocks light leakage.

A capping layer **80** is positioned on the color filter **230**. The capping layer **80** prevents the color filter **230** from being lifted and suppresses the contamination of the liquid crystal layer **3** due to an organic material, such as a solvent flowing from the color filter, thereby preventing defects that may otherwise result when a screen is driven, such as an after-image.

A second subpixel electrode **191***b* is formed on the capping layer **80**. The second subpixel electrode **191***b* forms part of a basic electrode **199** illustrated in FIG. **3** or one or more modifications thereof. Here, the basic electrode **199** includes a pixel electrode **191** including a first subpixel electrode **191***a* and the second subpixel electrode **191***b*, and a common electrode **270**. A plurality of patterns of the basic electrode **199** may be connected to each other in one pixel area. For example, the liquid crystal display may include two to four basic electrodes **199** in one pixel area. Hereinafter, the pixel electrode **191** including the first and second subpixel electrodes **191***a* and **191***b* is described with respect to the basic electrode **199**.

A second passivation layer **180***b* is formed on the second subpixel electrode **191***b*, and the first subpixel electrode **191***a* is formed on the second passivation layer **180***b*. The first subpixel electrode **191***a* includes a basic electrode **199** illustrated in FIG. **3** or one or more modifications thereof.

The second subpixel electrode **191***b* is formed to substantially surround the first subpixel electrode **191***a*.

The first subpixel electrode **191***a* includes a first plate portion **192***a*, a first stem **193***a*, and a plurality of first branches **194***a* (e.g., including **194***a***1**, **194***a***2**, **194***a***3** and **194***a***4**). The first subpixel electrode **191***a* has a substantially rhombus shape except for a protrusion **193***a***2**, which is an end portion of the first stem **193***a* and described below. The outline of the rhombus shape coincides with a virtual line connecting edges of the first branches **194***a*. The first plate portion **192***a* is positioned at the center of the first subpixel electrode **191***a*, the first stem **193***a* extends from the first plate portion **192***a* in a cross shape, and the first branches **194***a* extend from the first plate portion **192***a* and the first stem **193***a*.

The first plate portion **192***a* has a substantially rhombus shape and is formed as an entire plate that does not include any cutout inside, and the perimeter thereof is surrounded by the first stem **193***a* and the first branch **194***a*. A diagonal direction of the rhombus shape formed by the first plate portion **192***a* may coincide with a diagonal direction of the rhombus shape formed by the first subpixel electrode **191***a*.

A first length **l1** corresponding to a distance from the center of the first plate portion **192***a* to one side may be about 14 μm or less. When the first length **l1** is longer than about 14 μm, control force for the liquid crystal molecules decreases in a first region **A1** (see FIG. **7**) around the first plate portion **192***a* and a driving time of the liquid crystal display increases. As a result, texturing in the first region **A1** may occur and the transmittance may deteriorate. When the size of the first plate portion **192***a* is limited, the length of the first branches **194***a* may be relatively increased. Longer first branches **194***a* allows the liquid crystal molecules to be controlled by a fringe field generated in the first branches **194***a* (more specifically, a cross portion **194***a***1**) in the first region **A1**. A detailed experimental result for the first length **l1** is described below.

The first stem **193***a* extends through a vertex of the rhombus shape of the first subpixel electrode **191***a* from a corresponding vertex of the rhombus shape of the first plate portion **192***a*. The protrusion **193***a***2** extending through the vertex of the rhombus shape overlaps with a second plate portion **192***b* of the second subpixel electrode **191***b* to be described below. That is, the first stem **193***a* includes a cross portion **193***a***1** that is disposed inside the rhombus shape of the first subpixel electrode **191***a* and free from overlap with (i.e., does not overlap) with the second plate portion **192***b*, and includes a protrusion **193***a***2** that extends from the cross portion **193***a***1** beyond the rhombus shape of the first subpixel electrode **191***a* and overlaps with the second plate portion **192***b*.

The first branches **194***a* extending from the first plate portion **192***a* and the first stem **193***a* (more specifically, the cross portion **193***a***1**) extend in four directions. That is, the first branches **194***a* include a plurality of first minute branches **194***a***1** extending obliquely in an upper right direction from the first plate portion **192***a* and the first stem **193***a*, a plurality of second minute branches **194***a***2** extending obliquely in a lower right direction, a plurality of third minute branches **194***a***3** extending obliquely in a lower left direction, and a plurality of fourth minute branches **194***a***4** extending obliquely in an upper right direction, such as shown in FIG. **4**. The outline of the outer edges of the minute branches **194***a***1** to **194***a***4** forms the rhombus shape of the first subpixel electrode **191***a*.

The second subpixel electrode **191***b* includes a second plate portion **192***b* and a plurality of second branches **194***b*. The second plate portion **192***b* surrounds the plurality of first branches **194***a* of the first subpixel electrode **191***a* on a plane, and the second branches **194***b* extend from the second plate portion **192***b*.

The second plate portion **192***b* has a similar shape to a shape in which four parallelogram plates positioned outside the first to fourth minute branches **194***a***1** to **194***a***4** of the first subpixel electrode **191***a* are combined. The second plate portion **192***b* generally has an overall shape of a rhombus that has its vertex portions removed and includes an opening **192***bo* in the shape of a rhombus. Accordingly, the second plate portion **192***b* generally has a shape similar to a quadrangular ring.

Similar to the first branches **194***a* of the first subpixel electrode **191***a*, the second branches **194***b* of the second subpixel electrode **191***b* include a plurality of fifth minute branches **194***b***1** extending obliquely in an upper right direction from the second plate portion **192***b*, a plurality of sixth minute branches **194***b***2** extending obliquely in a lower right direction, a plurality of seventh minute branches **194***b***3** extending obliquely in a lower left direction, and a plurality of eighth minute branches **194***b***4** extending obliquely in an upper right direction, such as shown in FIG. **5**.

The directions in which the first to fourth minute branches **194***a***1** to **194***a***4** and the fifth to eighth minute branches **194***b***1** to **194***b***4** extend may form angles of about 45 degrees or 135 degrees with the direction in which the gate line **121** extends. The first to fourth minute branches **194***a***1** to **194***a***4** and the fifth to eighth minute branches **194***b***1** to **194***b***4** may form angles of about 45 degrees or 135 degrees with the first stem **193***a*. Further, the minute branches extending in different directions may be orthogonal to each other (for example, the first minute branches **194***a***1** and the second minute branches **194***a***2**) or parallel to each other (for example, the first minute branches **194***a***1** and the third minute branches **194***a***3**). As such, the first branches **194***a* of the first subpixel electrode **191***a* and the second branches **194***b* of the second subpixel electrode **191***b* have the plurality of minute branches (**194***a***1**, **194***b***1**; **194***a***2**, **194***b***2**; **194***a***3**, **194***b***3**; **194***a***4**, **194***b***4**) extending in different directions to form four domains in which tilted directions of the liquid crystal molecules are differently controlled. As a result, a viewing angle of the liquid crystal display is increased.

When the first subpixel electrode **191***a* and the second subpixel electrode **191***b* are overlay as shown in FIG. **3**, the outer edges/edge portions of the first to fourth minute branches **194***a***1** to **194***a***4** may coincide with or slightly overlap with the edges/edge portions of the opening **192***bo*. In more detail, in a plan view, an edge adjacent to the second plate portion **192***b* among the outer edges of the first branches **194***a* of the first subpixel electrode **191***a* and an edge adjacent to the first subpixel electrode **191***a* among the inner edges of the second plate portion **192***b* of the second subpixel electrode **191***b* may coincide each other or slightly overlap with each other. In other words, the rhombus shape formed the outline of the outer edges of the first branches **194***a* and the rhombus shape of the opening **192***bo* of the second plate portion **192***b* may substantially coincide with each other. However, the protrusion **193***a***2** of the first stem **193***a* of the first subpixel electrode **191***a* may generally overlap with the second plate portion **192***b*, such as shown in FIG. **3**. According to an exemplary embodiment, the protrusion **193***a***2** may extend past a most outer edge of the second plate portion **192***b*. In this case, the end of the protrusion **193***a***2** may not overlap with the second plate portion **192***b*.

A first contact hole **185***a* exposing a part of the first drain electrode **175***a* and a second contact hole **185***b* exposing a part of the second drain electrode **175***b* are formed in the first passivation layer **180***a*, the color filter **230**, the capping layer **80**, and the second passivation layer **180***b*. An extension **136** of the reference voltage line **131** and a third contact hole **185***c* exposing the third drain electrode **175***c* are formed in the gate insulating layer **140**, the first passivation layer **180***a*, the color filter **230**, the capping layer **80**, and the second passivation layer **180***b*.

A first extension **195***a* of the first subpixel electrode **191***a* is physically and electrically connected to the first drain electrode **175***a* through the first contact hole **185***a*. A second extension **195***b* of the second subpixel electrode **191***b* is physically and electrically connected to the second drain electrode **175***b* through the second contact hole **185***b*.

The first subpixel electrode **191***a* and the second subpixel electrode **191***b* receive data voltages from the first drain electrode **175***a* and the second drain electrode **175***b* through the first contact hole **185***a* and the second contact hole **185***b*, respectively.

A connecting member **195** is formed on the extension **136** of the reference voltage line **131** exposed through the third contact hole **185***c* and the third drain electrode **175***c*. The third drain electrode **175***c* is physically and electrically connected to the extension **136** of the reference voltage line **131** through the connecting member **195**.

Next, the upper panel **200** is described.

A light blocking member **220** and a common electrode **270** are formed on a second insulation substrate **210**.

The common electrode **270** may be formed as a plate that does not include cutouts and patterns, such as shown in FIG. **6**.

Although FIG. **2** shows the light blocking member **220** as being formed on the upper panel **200**, the light blocking member **220** may be positioned on the lower panel **100**. Similarly, although the color filter **230** is described above as being positioned on the lower panel **100**, the color filter **230** may be positioned on the upper panel **200**.

Alignment layers (not illustrated) may be formed on the inner surfaces of the lower and upper panels **100** and **200** (i.e., the surfaces of the two panels facing each other) and may be vertical alignment layers.

A polarizer (not illustrated) may be provided on each of the two outer surfaces of the lower and upper panels **100** and **200**. The transmissive axes of the two polarizers may be orthogonal to each other. One of the transmissive axes may be parallel to the gate line **121**.

The liquid crystal layer **3** may have negative dielectric anisotropy, in which case, the long axis of the liquid crystal molecules of the liquid crystal layer **3** is aligned orthogonal to the surfaces of the two panels **100** and **200** when the electric field is not applied. Accordingly, incident light does not pass through the display panel and is blocked by the two polarizers having orthogonal transmissive axes when the electric field is not applied.

The first subpixel electrode **191***a* and the second subpixel electrode **191***b* to which the data voltages are applied generate the electric field together with the common electrode **270** of the upper panel **200**. As a result, the liquid crystal molecules of the liquid crystal layer **3**, which are aligned so as to be orthogonal to the surfaces of the two electrodes **191** and **270** when the electric field is not applied, are tilted in a horizontal direction with respect to the surfaces of the two electrodes **191** and **270**. The amount of light passing through the display panel varies according to the tilted degree of the liquid crystal molecules, and thus, the luminance of the pixels may be changed.

A liquid crystal display according to an exemplary embodiment of the present system and method is described above. Hereinafter, a driving method is described.

When a gate-on signal is applied to the gate line **121**, the gate-on signal is applied to the first gate electrode **124***a*, the second gate electrode **124***b*, and the third gate electrode **124***c* to turn on the first switching element Qa, the second switching element Qb, and the third switching element Qc. Accordingly, the data voltage applied to the data line **171** is transmitted to the first subpixel electrode **191***a* and the second subpixel electrode **191***b* through the turned-on first switching element Qa and second switching element Qb as a first voltage and a second voltage, respectively. In this case, although the same data voltage is applied to the data line **171**, the second voltage applied to the second subpixel electrode **191***b* is divided through the third switching element Qc connected in series with the second switching element Qb. Accordingly, the second voltage applied to the second subpixel electrode **191***b* is smaller than the first voltage applied to the first subpixel electrode **191***a*.

Because the magnitude of the second voltage applied to the second subpixel electrode **191***b* is smaller than the magnitude of the first voltage applied to the first subpixel electrode **191***a*, the difference in voltage between the first subpixel electrode **191***a* and the common electrode **270** is larger than the difference in voltage between the second subpixel electrode **191***b* and the common electrode **270**. Accordingly, charging voltages of a first liquid crystal capacitor formed between the first subpixel electrode **191***a* and the common electrode **270** and a second liquid crystal capacitor formed between the second subpixel electrode **191***b* and the common electrode **270** represent different gamma curves, and a gamma curve of one pixel voltage becomes a curve combining the gamma curves. A combined gamma curve at the front side coincides with a reference gamma curve at the front, which is most appropriately determined, and a combined gamma curve at the side closely approximates the reference gamma curve at the front. As such, side visibility is improved.

A ratio of the second voltage applied to the second subpixel electrode **191***b* to the first voltage applied to the first subpixel electrode **191***a* (second voltage/first voltage) may be about 0.83 or less. As the voltage ratio increases, particularly, in a second region A**2** (see FIG. **7**) around a portion where the second plate portion **192***b* of the second subpixel electrode **191***b* and the protrusion **193***a***2** of the first stem **193***a* of the first subpixel electrode **191***a* overlap with each other, the intensity of the fringe field generated at the edge of the protrusion **193***a***2** due to the second voltage decreases. When the voltage ratio is larger than about 0.83, the control force for the liquid crystal molecules in the second region A**2** may deteriorate and fail to suppress texturing and as a result, the transmittance and the image quality may deteriorate. Experimental results for various voltage ratios are described below.

As described above with respect to the exemplary embodiment of FIG. **1**, an output terminal of the second switching element Qb connected to the second subpixel electrode **191***b* configuring the second liquid crystal capacitor and the third switching element Qc connected to the divided reference voltage line are included so that the voltage charged in the first liquid crystal capacitor and the voltage charged in the second liquid crystal capacitor are different. In addition, various techniques for making the voltages charged in the first liquid crystal capacitor and the second liquid crystal capacitor different may be applied to the present system and method. Thus, even if the liquid crystal display does not include the third switching element Qc and constituent elements related with the switching element Qc (for example, the extension **136** of the reference voltage line **131**, the connecting member **195**, and the like), the side visibility may be improved, which is described below.

For example, as FIG. **2** shows, the first subpixel electrode **191***a* is formed on the second passivation layer **180***b*, and the second subpixel electrode **191***b* is formed below the second passivation layer **180***b*. Accordingly, a first gap g**1** between the first subpixel electrode **191***a* and the common electrode **270** is smaller than a second gap g**2** between the second subpixel electrode **191***b* and the common electrode **270**. As a result, even though the first subpixel electrode **191***a* and the second subpixel electrode **191***b* receive the data voltage having the same magnitude from the data line **171**, as described above, the intensity of the electric field generated between the first subpixel electrode **191***a* and the common electrode **270** is larger than the intensity of the electric field generated between the second subpixel electrode **191***b* and the common electrode **270**. Further, according to a dielectric constant of the second passivation layer **180***b*, the difference between the intensity of the electric field generated between the first subpixel electrode **191***a* and the common electrode **270** and the intensity of the electric field generated between the second subpixel electrode **191***b* and the common electrode **270** may be controlled.

Accordingly, charging voltages of a first liquid crystal capacitor formed between the first subpixel electrode **191***a* and the common electrode **270** and a second liquid crystal capacitor formed between the second subpixel electrode **191***b* and the common electrode **270** represent different gamma curves, and a gamma curve of one pixel voltage becomes a curve combining the gamma curves. A combined gamma curve at the front coincides with a reference gamma curve at the front, which is most appropriately determined, and a combined gamma curve at the side closely approximates the reference gamma curve at the front. As such, side visibility is improved.

As another example, the liquid crystal display may include an output terminal of the second switching element Qb connected to the second subpixel electrode **191***b* configuring the second liquid crystal capacitor and a third switching element Qc connected to a step-down capacitor. In this case, the third switching element Qc may be connected to a different gate line from the gate line to which the first switching element Qa and the second switching element Qb are connected. The third switching element Qc may be turned on after the first switching element Qa and the second switching element Qb are turned on and then turned off. When the third switching element Qc is turned on after switching elements Qa and Qb are turned off, charges move to the step-down capacitor through the third switching element Qc from the second subpixel electrode **191***b*. This causes the charging voltage of the second liquid crystal capacitor to decrease and the step-down capacitor to charge. Since the charging voltage of the second liquid crystal capacitor is decreased by the step-down capacitor, the charging voltage of the second liquid crystal capacitor is smaller than the charging voltage of the first liquid crystal capacitor.

As another example, the first liquid crystal capacitor and the second liquid crystal capacitor may be connected to different data lines and thus receive different data voltages. As a result, the charged voltages between the first liquid crystal capacitor and the second liquid crystal capacitor may be different from each other. In addition, by various different methods, the charged voltages between the first liquid crystal capacitor and the second liquid crystal capacitor may be differently set.

An alignment of the liquid crystal molecules in a region of the field generating electrode of the liquid crystal display according to an exemplary embodiment of the present system and method is described with reference to FIGS. **7** and **8**.

FIG. **7** is a schematic view illustrating alignment directions of directors of the liquid crystal molecules of the liquid crystal display according to an exemplary embodiment of the present system and method. FIGS. **8** and **9** are cross-sectional views illustrating alignment directions of directors of the liquid crystal molecules of the liquid crystal display according to an exemplary embodiment of the present system and method.

Referring to FIGS. **7** to **9**, a first fringe field F**1** is generated in a direction vertical to an edge (a first edge) of the second branches **194***b* of the second subpixel electrode **191***b*. Due to the effect of the first fringe field F**1**, first liquid crystal molecules **31***a* positioned around the second branches **194***b* are tilted in a direction parallel with the direction of the first fringe field F**1** and parallel with a longitudinal direction in which the second branch **194***b* extends.

A second fringe field F**2** is generated at an edge (a second edge) of the second plate portion **192***b* of the second subpixel electrode **191***b* adjacent to the second branch **194***b*. Due to the effect of the second fringe field F**2**, second liquid crystal molecules **31***b* positioned around the second edge are tilted in a direction vertical to the second edge, which is the same as the tilted direction of the first liquid crystal molecules **31***a*.

A third fringe field F**3** is generated at an edge (a third edge) of the second plate portion **192***b* of the second subpixel electrode **191***b* adjacent to the first branches **194***a*. Third liquid crystal molecules **31***c* positioned around the third edge are influenced by the third fringe field F**3** to be tilted in a direction vertical to the third edge of the second plate portion **192***b*. The direction is opposite to the tilted directions of the first liquid crystal molecules **31***a* and the second liquid crystal molecules **31***b*.

Further, a fourth fringe field F**4** is generated at an edge (a fourth edge) of the first branches **194***a* adjacent to the second plate portion **192***b* of the second subpixel electrode **191***b*. Fourth liquid crystal molecules **31***d* near the fourth edge are tilted in a direction vertical to the fourth fringe field F**4**. The direction is the same as the tilted directions of the first liquid crystal molecule **31***a* and the second liquid crystal molecule **31***b*.

As described above, the intensity of the electric field formed between the first subpixel electrode **191***a* and the common electrode **270** is greater than the intensity of the electric field formed between the second subpixel electrode **191***b* and the common electrode **270**. Further, the intensity of the third fringe field F**3** is reduced due to shielding by the first branches **194***a*. Therefore, the intensity of the fourth fringe field F**4** is larger than that of the third fringe field F**3**. Accordingly, the liquid crystal molecules positioned around the boundary of the first subpixel electrode **191***a* and the second subpixel electrode **191***b* are influenced to a greater extent by the fourth fringe field F**4**, which has a greater intensity than the third fringe field F**3**. Thus, the third liquid crystal molecules **31***c* are tilted in a direction parallel to that of the nearby second and fourth liquid crystal molecules **31***b* and **31***d*. Accordingly, texturing does not occur around the boundary of the first subpixel electrode **191***a* and the second subpixel electrode **191***b*, and the luminance of the liquid crystal display is increased.

A fifth fringe field F**5** is generated at an edge (fifth edge) of the first branch **194***a*. Fifth liquid crystal molecules **31***e* near the first branch **194***a* of the first subpixel electrode **191***a* are influenced by the fifth fringe field F**5** to be tilted in a direction parallel with the fifth fringe field F**5** and parallel with the longitudinal direction in which the first branch **194***a* extends.

A sixth fringe field F**6** is generated at an edge (sixth edge) of the first plate portion **192***a*. Sixth liquid crystal molecules **31***f* near the first plate portion **192***a* of the first subpixel electrode **191***a* are influenced by the sixth fringe field F**6** to be tilted in the same direction as the tilted direction of the fifth liquid crystal molecules **31***e*.

In the second region A**2** around the portion where the second plate portion **192***b* of the second subpixel electrode **191***b* and the protrusion **193***a***2** of the first stem **193***a* of the first subpixel electrode **191***a* overlap each other, a seventh fringe field F**7** and an eighth fringe field F**8** are generated at both edges (seventh and eighth edges) of the protrusion **193***a***2**, respectively. Seventh liquid crystal molecules **31***g* positioned around the seventh edge are tilted in a direction vertical to the seventh edge by the seventh fringe field F**7** and parallel with the extending direction of the first branch **194***a* by influence of neighboring liquid crystal molecules, which are also tilted in the direction parallel with the extending direction of the first branch **194***a*. Eighth liquid crystal molecules **31***h* positioned around the eighth edge are also tilted in a direction parallel with the extending direction of the first branch **194***a* by the seventh fringe field F**7** and the tilted direction of the neighboring liquid crystal molecules.

Accordingly, even though cutouts for controlling the seventh and eighth liquid crystal molecules in the second region A**2** are not formed at the common electrode **270**, the seventh and eighth liquid crystal molecules are controlled by the protrusion **193***a***2** of the first stem **193***a* of the first subpixel electrode **191***a*, thereby suppressing texturing that may otherwise be generated in the second region A**2** and improving the luminance. According to the exemplary embodiment shown in FIG. **6**, the cutouts are not formed at the common electrode **270** to prevent a loss of transmittance which may be generated by misalignment of the cutouts of the common electrode **270** and the pixel electrode **191**. Further, a mask and a process for forming the cutouts at the common electrode **270** are not required.

Next, some Experimental Examples of the present system and method are described with reference to FIGS. **10** to **15**.

FIGS. **10**A, **10**B, **10**C and **10**D are electron microphotographs illustrating results of a first experimental example of the present system and method.

Referring to FIGS. **10**A, **10**B, **10**C and **10**D, in the liquid crystal display having the pixel structure according to the exemplary embodiment of FIGS. **1** to **6**, changes in luminance by varying the ratio of the second voltage applied to the second subpixel electrode **191***b* to the first voltage applied to the first subpixel electrode **191***a* are illustrated in electron microphotographs. FIGS. **10**A, **10**B, **10**C and **10**D illustrate results when the voltage ratios are 0.77, 0.8, 0.83, and 0.86, respectively. Since the tilted direction of the liquid crystal molecules are opposite to each other on a domain boundary, which substantially coincides with the first branches **194** of the first subpixel electrode **191***a*, the domain boundary is illustrated to be relatively dark. When the voltage ratio is 0.83 or less, it can be seen that the direction of the liquid crystal molecules on the domain boundary is controlled well except for typical transmittance deterioration. However, when the voltage ratio is 0.86, texturing having a ring shape is generated in the second region A**2**, and as a result, the transmittance is reduced as compared with the cases in which the voltage ratio is 0.83 or less. It is understood that the texturing occurs because the size of the fringe field controlling the liquid crystal molecules in the second region A**2** becomes so small that it cannot suppress the generation of the textures when the voltage ratio is larger than 0.83.

FIGS. **11**A, **11**B and **11**C are electron microphotographs illustrating results of a second experimental example of the present system and method.

Referring to FIGS. **11**A, **11**B and **11**C, in the liquid crystal display having the pixel structure according to the exemplary embodiment of FIGS. **1** to **6**, results of experiments in which the ratio of the first plate portion **192***a* and the first branch **194***a* of the first subpixel electrode **191***a* and the second plate portion **192***b* and the second branch **194***b* of the second subpixel electrode **191***b* is changed while maintaining the entire size of the pixel electrode **191** is illustrated.

FIGS. **11**A, **11**B and **11**C illustrate cases in which lengths l**1**, l**2**, l**3**, and l**4** of the pixel electrode **191** (see FIG. **3**) are formed to be 11 μm, 25 μm, 21 μm, and 29 μm; 14 μm, 22 μm, 25 μm, and 25 μm; and 17 μm, 22 μm, 23.5 μm, and 23.5 μm, respectively. The first length l**1** corresponds to a distance from the center of the first plate portion **192***a* to one side. The second length l**2** corresponds to a length of the first branch **194***a* extending from one side of the first plate portion **192***a*. The third length l**3** represents corresponds to a gap between an inner side and a right side of the second plate portion **192***b* that are adjacent to each other. And the fourth length l**4** corresponds to a largest length of the second branch **194***b*. The sum of the lengths l**1**, l**2**, l**3**, and l**4** is substantially equal to half of the diagonal length of the pixel electrode **191** configuring the basic electrode **199**.

The three upper photographs of FIGS. **11**A, **11**B and **11**C are electron microphotographs taken 130 ms after each case is driven. The three lower photographs of FIGS. **11**A, **11**B and **11**C are electron microphotographs taken 300 ms after each case is driven. In the cases of FIGS. **11**A and **11**B in which the first distance l1 is 11 μm and 14 μm, respectively, it can be seen that even though the driving time elapses, the liquid crystal molecules are controlled well over the entire area. However, when the first distance l1 is 17 μm, as in the case of FIG. 11C, it can be seen that in the first region A1 around the first plate portion 192*a*, the control force for the liquid crystal molecules is decreased and the transmittance is reduced. It is understood that this is caused because the length of the first branches 194*a* is decreased as the size of the first plate portion 192*a* is increased, and thus, influence by the fringe field of the first branches 194*a* in the first region A1 is reduced.

Data measured with respect to a change in luminance according to the size of the first plate portion 192*a* are described with reference to FIGS. 12 and 13.

FIGS. 12 and 13 are graphs illustrating results of a third experimental example of the present system and method.

FIG. 12 is a graph illustrating a change in transmittance over time for varying sizes of the first plate portion 192*a*. FIG. 13 is a graph of the transmittance of FIG. 12 normalized as luminance. An experiment is performed with respect to four cases in which the sum of the first length l1 and the second length l2 of the first subpixel electrode 191*a* is maintained at 36 μm, while increasing the first length l1 and decreasing the second length l2. The size of the second subpixel electrode 191*b* is also maintained in the four cases so as to maintain the area ratio. In each graph, a one-dot dashed line represents a case in which l1 and l2 are 8 μm and 28 μm, respectively, a two-dot dashed line represents a case in which l1 and l2 are 11 μm and 25 μm, respectively, a solid line represents a case in which l1 and l2 are 14 μm and 22 μm, respectively, and a dotted line represents a case in which l1 and l2 are 17 μm and 19 μm, respectively.

As illustrated in the two graphs, it can be seen that when the first length l1 is 14 μm, deterioration of luminance over time after reaching maximum luminance is significantly less than when the first length l1 is 17 μm. Accordingly, when the first length l1 is larger than 14 μm, defects of image quality such as deterioration of luminance or generation of after-images may become problematic.

FIGS. 14A, 14B, 15A and 15B illustrate structures of a first subpixel electrode, and their corresponding electron microphotographs, used in a fourth experimental example and a result thereof.

FIG. 14 illustrates a case in which the first stem 193*a* of the first subpixel electrode 191*a* includes the protrusion 193*a*2 and the second plate portion 192*b* of the second subpixel electrode 191*b* overlaps with the protrusion 193*a*2 in the second region A2, like the exemplary embodiment of FIGS. 1 to 6. On the other hand, FIG. 15 illustrates a case in which the first stem 193*a* of the first subpixel electrode 191*a* does not include the protrusion 193*a*2 but only includes a part corresponding to the cross portion 193*a*1. FIGS. 14A and 15A illustrate the structure of the first subpixel electrode 191*a*. FIGS. 14B and 15B illustrate the electron microphotographs.

Referring to FIG. 14B, it can be seen that the luminance is deteriorated only on the boundary of the domain, meaning the liquid crystal molecules in the second region A2 are controlled well. However, referring to FIG. 15B, it can be seen that the luminance is deteriorated on the boundary of the domain and around the boundary. It is understood that the difference in the result occurs because the liquid crystal molecules in the second region A2 are controlled by the fringe field generated in the protrusion 193*a*2 according to the exemplary embodiment of the present system and method.

While the present system and method are described above in connection with exemplary embodiments, the present system and method are not limited to the disclosed embodiments. On the contrary, the present system and method are intended to cover various modifications and equivalent arrangements.

What is claimed is:

1. A liquid crystal display, comprising:

a lower panel including a pixel electrode having a first subpixel electrode and a second subpixel electrode and an insulating layer disposed between the first subpixel electrode and the second subpixel electrode;

an upper panel including a common electrode; and

a liquid crystal layer disposed between the lower panel and the upper panel,

wherein the first subpixel electrode includes a first plate portion, a first stem having a cross portion extending from the first plate portion in a cross shape and a protrusion extending from the cross portion, and a plurality of first branches extending from the first plate portion and the first stem,

the second subpixel electrode includes a second plate portion having an opening therein and a plurality of second branches extending from the second plate portion, and

the cross portion is free from overlap with the second plate portion and the protrusion overlaps with the second plate portion.

2. The liquid crystal display of claim 1, wherein:

the first subpixel electrode is positioned on the insulating layer and the second subpixel electrode is positioned below the insulating layer.

3. The liquid crystal display of claim 2, wherein:

the common electrode is formed as a plate.

4. The liquid crystal display of claim 2, wherein:

the second plate portion surrounds the plurality of first branches.

5. The liquid crystal display of claim 4, wherein:

the opening of the second plate portion has a planar, rhombus shape.

6. The liquid crystal display of claim 5, wherein:

an edge of the first branch and an edge of the second plate portion adjacent to the first branch coincide with each other.

7. The liquid crystal display of claim 5, wherein:

an edge of the first branch and an edge of the second plate portion adjacent to the first branch overlap with each other.

8. The liquid crystal display of claim 1, wherein:

the first plate portion has a planar, rhombus shape.

9. The liquid crystal display of claim 8, wherein:

a length corresponding to a distance from the center of the rhombus shaped first plate portion to one side is about 14 μm or less.

10. The liquid crystal display of claim 8, wherein:

the first stem extends in a diagonal direction of the rhombus shaped first plate portion.

11. The liquid crystal display of claim 1, wherein:

the first subpixel electrode is configured to receive a first voltage, the second subpixel electrode is configured to receive a second voltage, and

a ratio of the second voltage to the first voltage is about 0.83 or less.

12. The liquid crystal display of claim 1, wherein:

the plurality of first branches includes a plurality of minute branches extending in four different directions, and the plurality of second branches includes a plurality of minute branches extending in the four different directions.

13. The liquid crystal display of claim **12**, wherein:

the four different directions are orthogonal to each other or parallel to each other.

14. The liquid crystal display of claim **1**, wherein:

the plurality of first branches extends from portions of the first stem excluding the protrusion.

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